

Figure 11. In-Vehicle Signing Installation Group (with channel assignments)

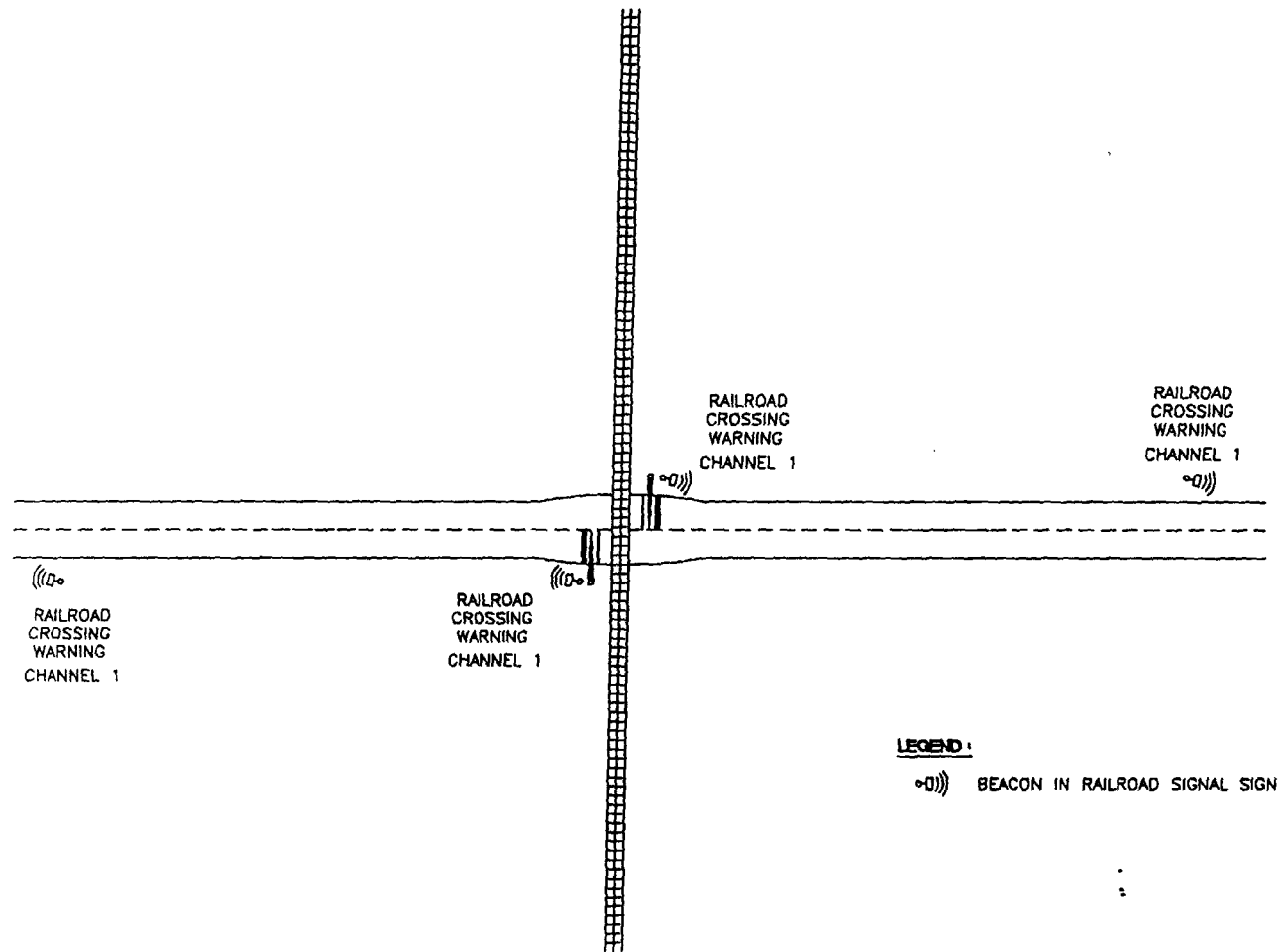


Figure 12. Railroad Crossing Warning (with channel assignment)

3.5.2 CVO Installation Group Channel Usage

The CVO installation group applications (electronic clearance, international border clearance, safety inspection, fleet management, and intermodal freight management) are implemented by using the assigned channels 3 and 4. Electronic clearance and safety inspection are implemented as shown in Figure 13. Electronic clearance is currently implemented by installing weigh in motion (WIM) scales in the roadway and antennas mounted above the roadway that are spaced about 1/2 mile upstream of the pass verification reader. These beacons both use channel 3, but are spaced far enough apart axially to avoid interference. Any in-vehicle signing placed between the two would not interfere because it would be on channel 1. The beacons used in the ramp sorter position and exit reader position are directed away from the mainline of the other beacons to prevent interference. The tag update reader in the inspection area would use channel 4 to prevent interference. The most frequent potential source of interference would be the mobile location interrogation and that would use channel 5.

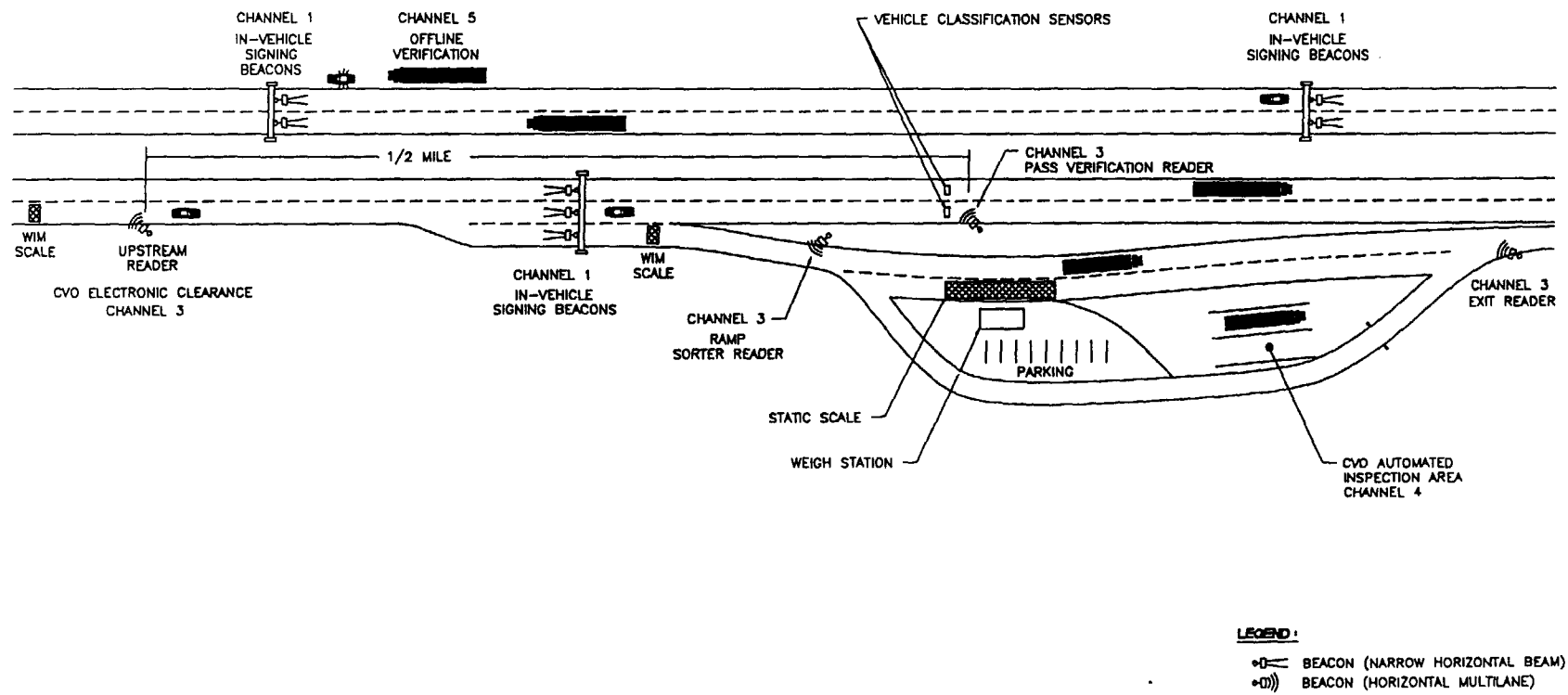


Figure 13. CVO Installation Group (with channel assignments)

International border clearance could be implemented as shown in Figure 14. One set of antennas are installed above the roadway about 1/2 mile before the border crossing. The second upstream reader could use channel 4. Reader one, the lock tag reader, could use a frequency from the 902-928 MHz band or channel 4 (See Appendix B). The 902-928 MHz band is being very heavily populated with the AEI devices that identify containers and trailers for freight management. Since this is not a common application among all vehicles and the 902-928 MHz devices have propagation advantages for freight yard use it is desirable to continue using the 902-928 band for the freight management and lock tag purpose. However, if just the lock tag function were moved, the first and second beacons could both use channel 4. They would not interfere with each other because they would be used sequentially. The in-vehicle signing placed between two and three would not interfere because it would be on channel 1. The lane sorter, verification and exit beacons are sighted in different directions to prevent interference with each other and would use channel 3 to prevent interference with the portable reader in the inspection area. The hand-held reader would use channel 4.

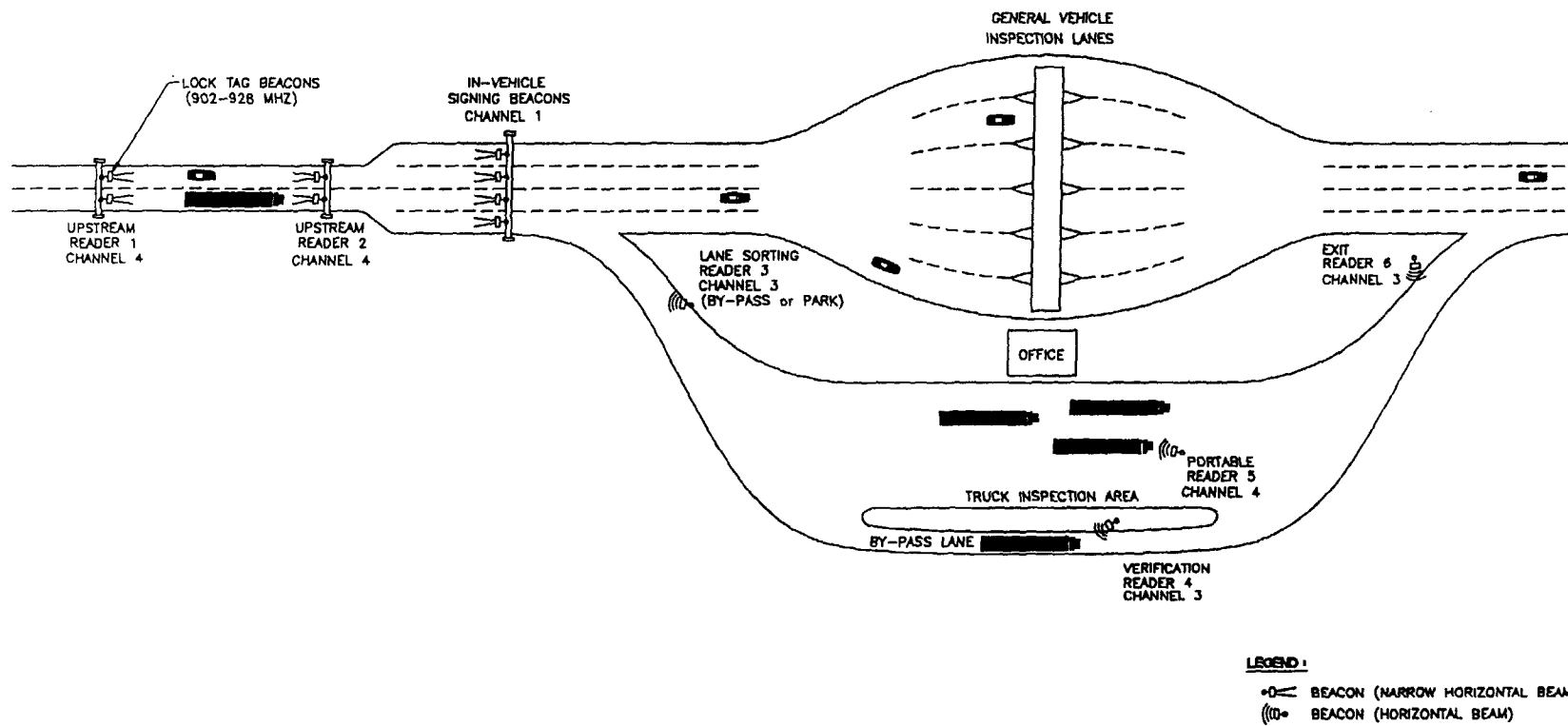


Figure 14. CVO Installation Group - International Border Clearance - with Channel Assignments

3.5.3 Intersection Installation Group

The applications in the intersection installation group (intersection collision avoidance, emergency vehicle signal preemption, and transit vehicle signal priority) are implemented by installing beacons in each direction of on-coming vehicles in the intersection as shown in Figure 15. Channels 1 and 2 are alternated between beacons to prevent cross-reads from intersecting lanes and interference from adjacent intersections. If no cooperating intersections are located upstream, at least two other sets of beacons should be employed on the alternate upstream channel: one at the range limit of the intersection beacon and another 2000 to 3000 feet away to implement collision avoidance and signal preemption. Intersection beacons are expected to use TDMA slotted aloha or similar protocol to communicate with multiple vehicles in the two or three approaching lanes. The transit vehicle data transfer is usually accomplished within the range of the intersection beacon but since it is operating on channel 3, and the vehicle is partially blocking the signal, this does not cause interference. Mobile location interrogation can also occur close to the intersection, but does not cause interference because it operates on channel 5. Four channels could be used in this application.

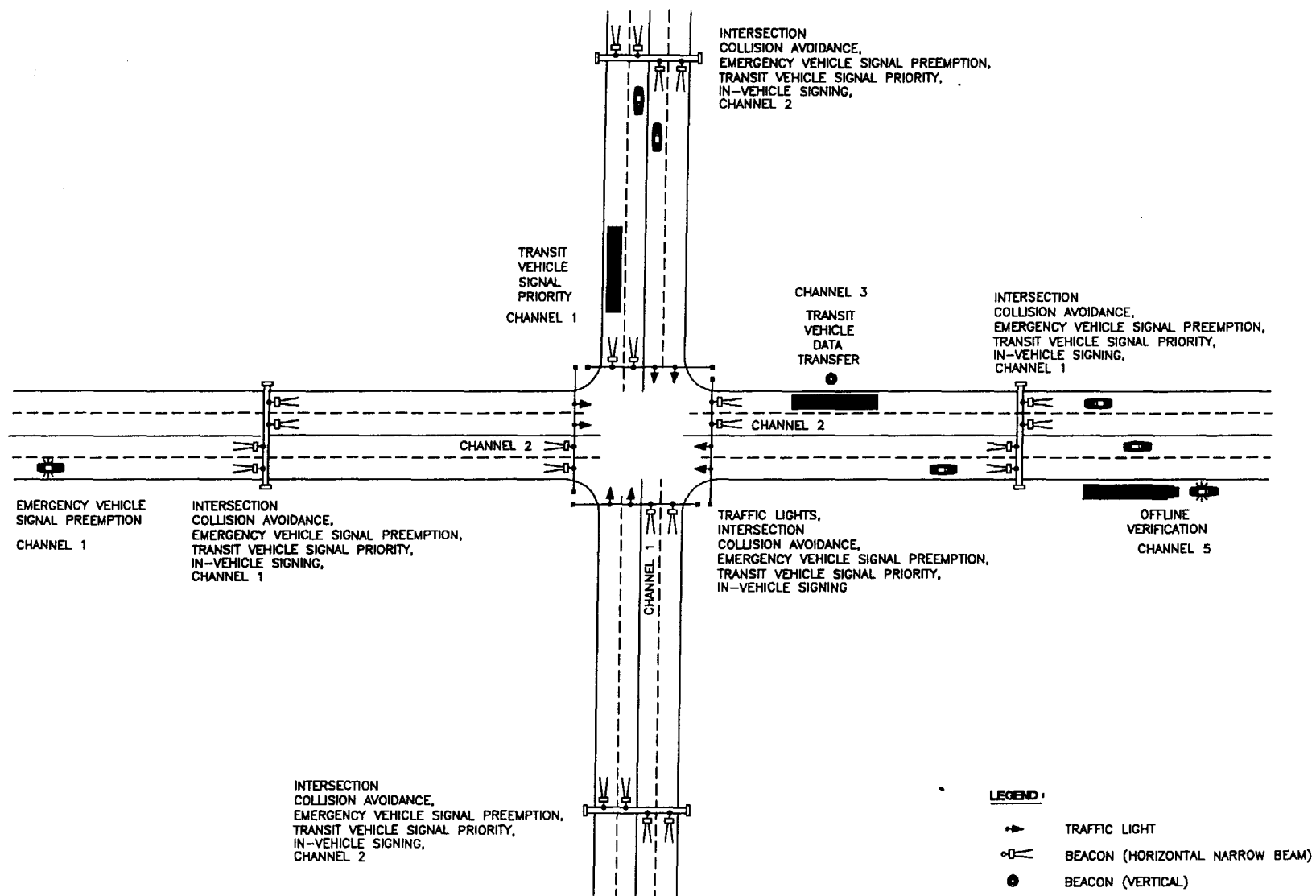


Figure 15. Intersection Installation Group (with channel assignments)

3.5.4 Automated Highway System-to-Vehicle Communications

Automated highway system-to-vehicle communications transfers data on the operational status and position of the AHS vehicle from the vehicle to the roadside, and transfers AHS operation instructions and AHS roadway status from the roadside to the vehicle (see Figure 16). AHS installations will operate on channel 6. Therefore, the location close to the in-vehicle signing or other applications does not cause interference.

3.5.5 Electronic Toll Collection (ETC)

In electronic toll collection, beacons are placed on gantries above toll lanes, and tags are attached to the windshield or license plate of vehicles (see Figure 17). Channels 3 and 4 are alternated between lanes to prevent cross lane interference because they are located close together. In addition, the manual toll collection area is also instrumented with antennas and readers that alternate between channels 3 and 4 to allow under-funded tags to have additional funds added. In-vehicle signing does not interfere because it operates on channel 1. AHS operations do not interfere because they operate on channel 6. Mobile location interrogation does not interfere because it operates on channel 5. In addition, if an intersection were nearby, it would not be interfered with because it would operate on channel 2 with channel 1 as its alternate.

3.5.6 Parking Payment / Access Control

The parking payment or access control application is implemented by placing antennas above the lanes entering the parking area and attaching tags to the windshield or front of vehicles (see Figure 18). Channels 3 and 4 are alternated between lanes to prevent cross lane interference because they are located close together. In addition, a low power setting is used because the capture zone is small and the vehicles are not moving fast. In this example, the transit vehicle data transfer would use channel 4, which is not the most proximate channel being used.

3.5.7 Drive-Thru Payment

In drive-thru payment, beacons are placed close to where the vehicle stops for service and tags are attached to the windshield or license plate of vehicles (see Figure 19). Channels 7 and 8 are alternated between lanes or between business locations to prevent interference. The reuse distance on each channel is small because a low power setting is used for the small capture zone.

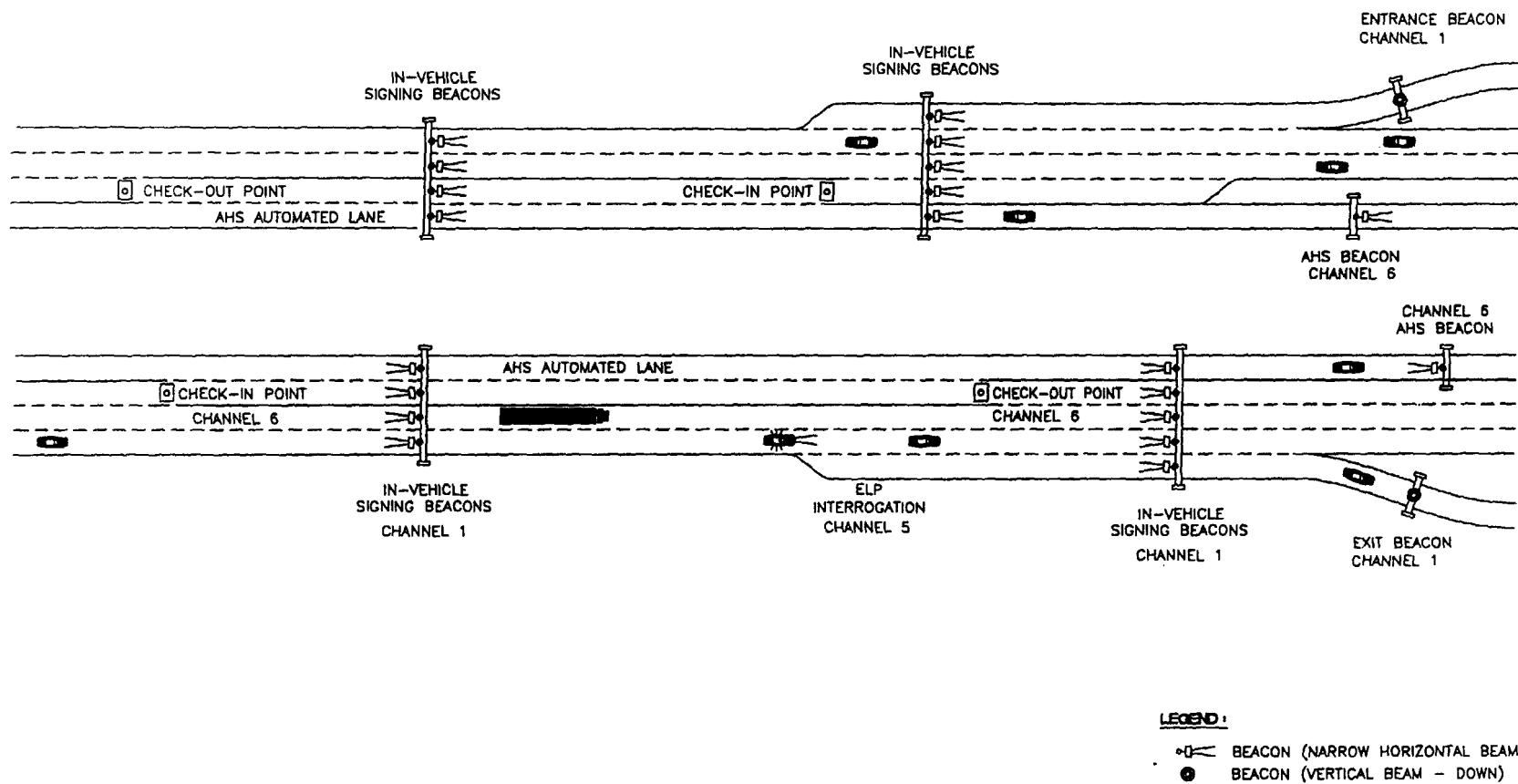


Figure 16. Automated Highway System to Vehicle Communications (with channel assignments)

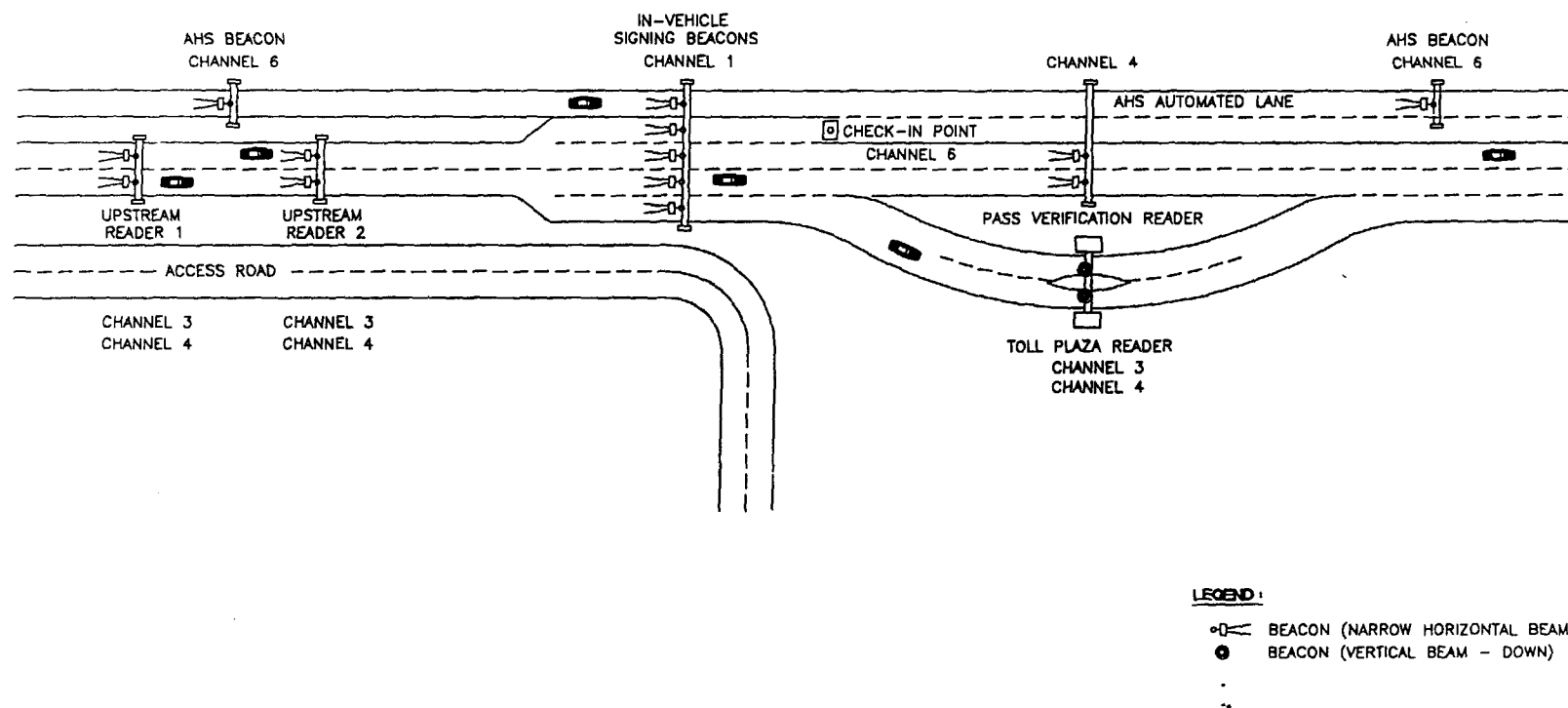


Figure 17. Electronic Toll Collection (with channel assignments)

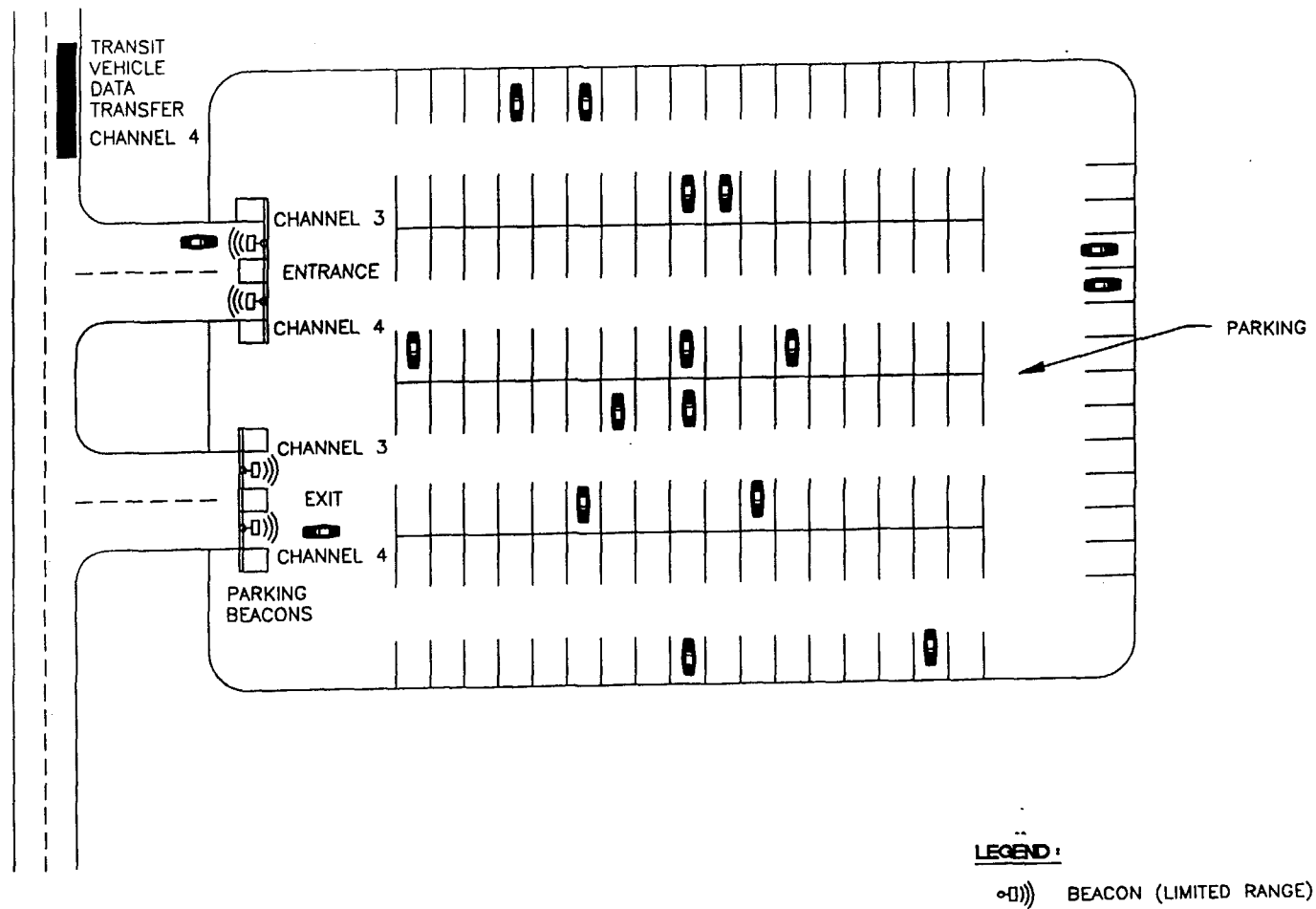


Figure 18. Parking Payment / Access Control Application
(with channel assignments)

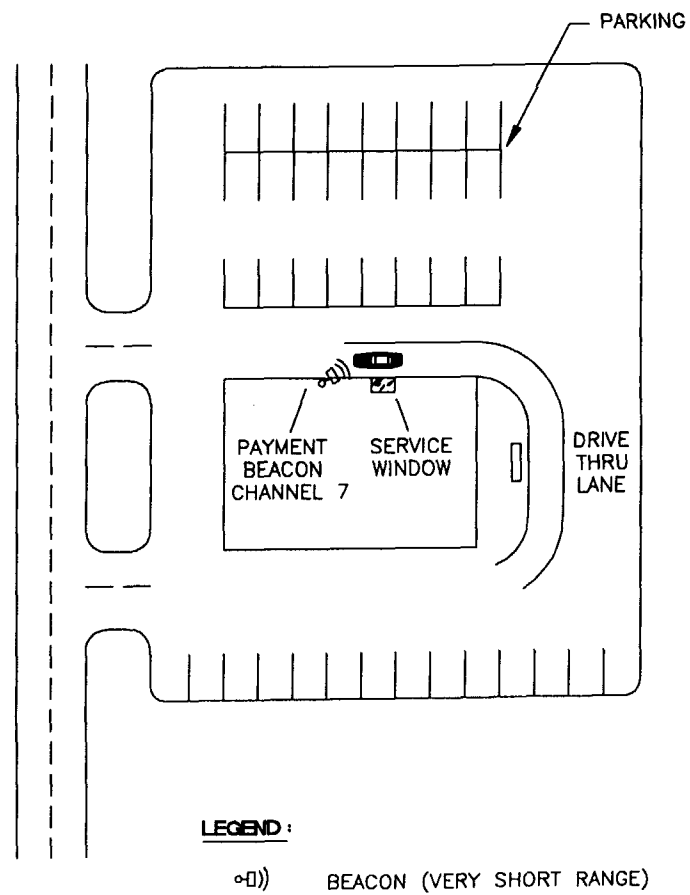


Figure 19. Drive-thru Business with channel assignment

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3.5.8 Close Proximity Multiple Application Implementation

This subsection presents a worst-case scenario examining an exceptionally dense collection of applications in one location. In compiling this scenario, it was assumed that a set of routine techniques that allow channel sharing and channel reuse will be used to meet the number of channels allocated in the previous section. This implementation includes an intersection installation group, mobile location interrogation group, transit application, in-vehicle signing group, railroad crossing application, and parking application. Figure 20 shows an actual intersection with DSRC beacons added in several likely locations assuming a full DSRC system implementation. It is intended to be a dense environment of DSRC in order to assess interference mitigation schemes and channel assignment requirements. Beacons shown in Figure 18 include horizontal beacons intended for directional area coverage, and vertical beacons intended to cover a single lane and communicate with vehicles individually. Labels on individual beacons are explained in the following paragraphs.

Using the analyses presented in the earlier sections, the beacons shown in Figure 20 will be assigned channels and mitigation of interference between beacons will be discussed to explain the logic of the assignment. These assignments are listed in Table 3 below. Note that careful timing and coordination between the beacons is required to implement the installations using this channel assignment scheme.

Table 3. Final Suggested Assignment of Channels to Beacons in Example Intersection

Beacon	Channel	Beacon	Channel	Beacon	Channel	Beacon	Channel
A	1	K	2	U	1	EE	3
B	1	L	2	V	1	FF	4
C	2	M	2	W	5	GG	3
D	2	N	1	X	3		
E	2	O	1	Y	4		
F	2	P	1	Z	4		
G	1	Q	1	AA	4		
H	1	R	2	BB	3		
I	2	S	2	CC	4		
J	2	T	1	DD	3		

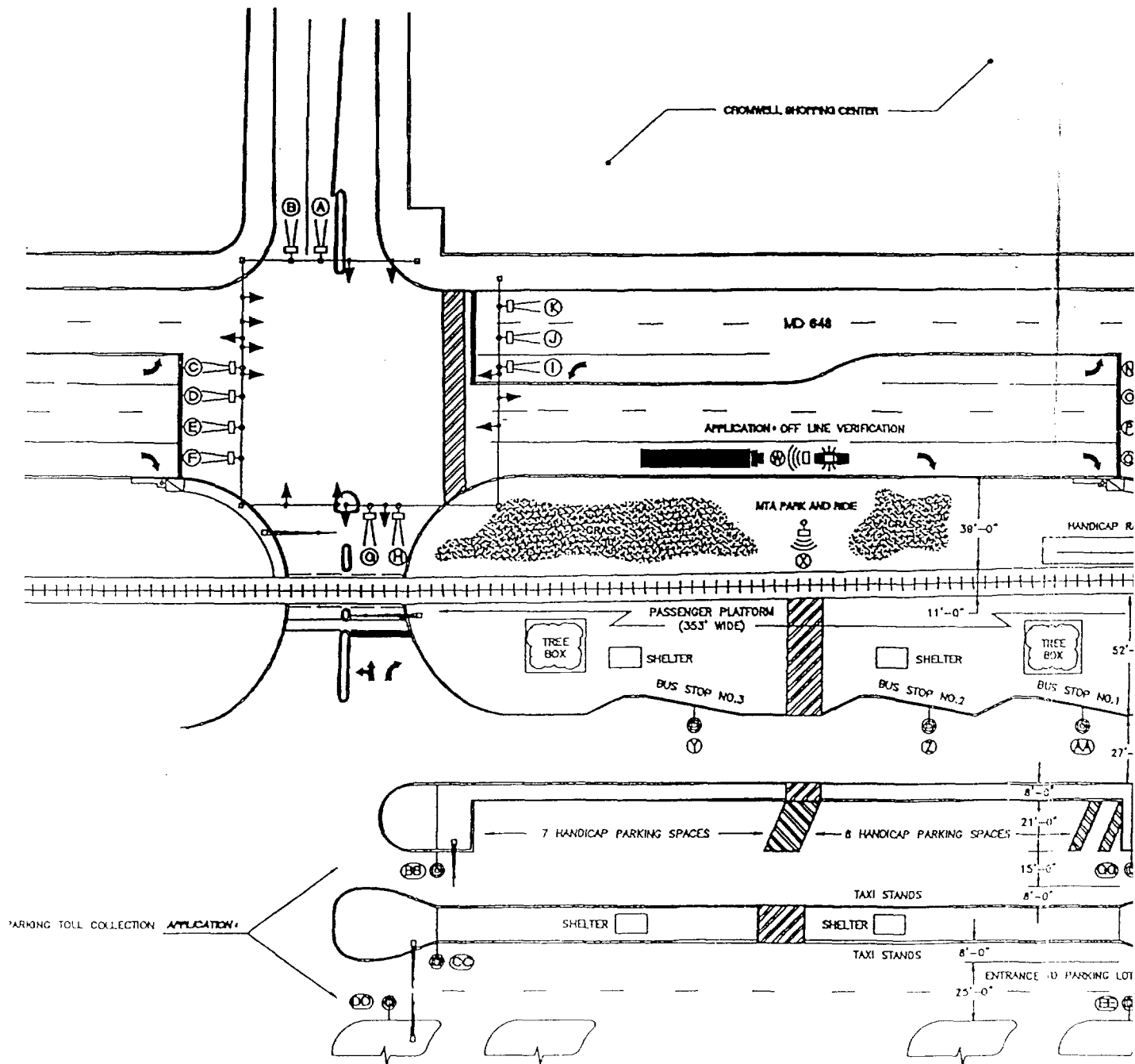
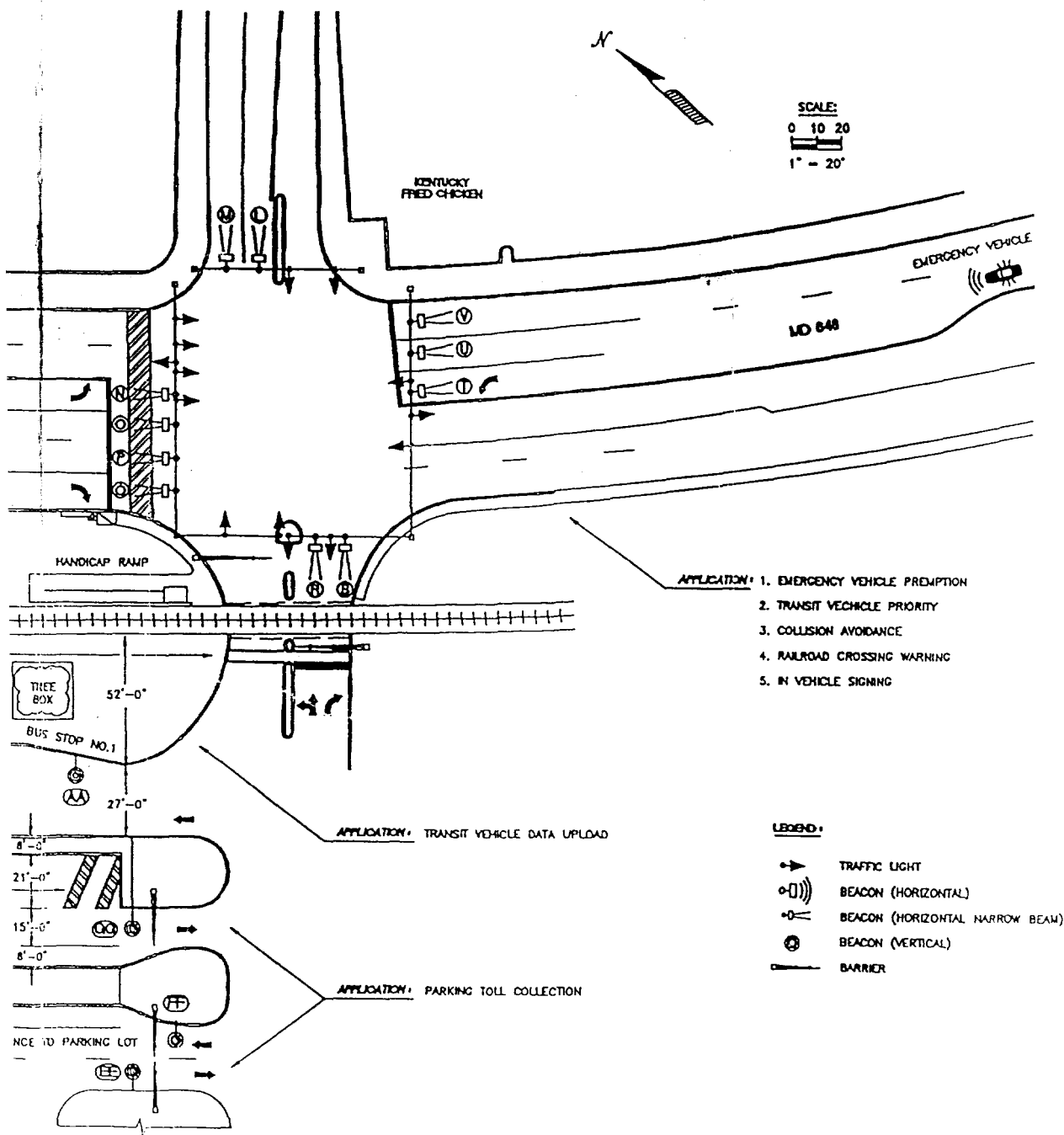


Figure 20. Multiple Group



le Group Installation

In this example, each direction of each intersection has one beacon in each lane for emergency vehicle preemption, transit vehicle priority, collision avoidance, railroad crossing warning and any in-vehicle signing required. No beacons are separately assigned to in-vehicle signing in this example, as intersection beacons are assumed to handle this function

Even with the number of channels used in the example intersection there is still a need for power control and spatial differentiation (antenna directivity) to mitigate interference between beacons. For example, the overhead parking beacons (BB - GG) must be carefully aimed and power controlled such that they do not communicate with tags of vehicles passing the parking zone on the roadway, or with the intersection beacons. Also, the power level of the beacon on the rail platform (X) that exchanges data with the Metro rail car (transit vehicle) must be kept as low as possible to avoid interfering with the three bus (transit vehicle) beacons (Y - AA). See Appendix D for sample calculations of channel reuse distances.

All three of the vertical beacons for bus (transit vehicle) data (Y - AA) are considered to be separated by enough distance to use a single channel at a very low power and small communication distances. The horizontal beacon on the rail platform is assigned another channel to mitigate any potential interference.

The mobile location interrogation beacon presents a unique scenario of interference between beacons. As described in Section 2.2, the reflected signal from the tag interrogated by the mobile location interrogation beacon includes a reflection of the intersection beacons that reach the tag. The interference caused by this reflection being received by the intersection beacon effectively reduces the range of the intersection beacon. Assume that the signal-to-interference ratio required for communications between the intersection beacon and another tag is 6 dB. The interference caused by the tag read by the off-line beacon reduces the operating range of the intersection beacon to 70 % of the distance from the intersection beacon to this tag. To mitigate the effects of this interference, the mobile location interrogation should reduce its operating time to the minimum required to complete data transfer. To minimize interference, the mobile location interrogation beacon should also synchronize with any in range stationary beacon, in an over the air link, and obtain an authorized slot sequence in which it can perform communications.

3.6 Summary of Channel Requirements

By using these mitigation techniques, the number of channels required to implement the DSRC systems can be reduced to 8 channels. Several special case situations were considered. Two channels were established for commercial operations so that they could be allocated under different rules, if necessary, and so that there would be no chance of interference with safety critical operations. The AHS function was assigned a single channel to provide an unmistakable and secure channel in which to operate AHS DSRC functions. The same rationale was used to enable a second intersection channel.

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4.0 DSRC DATA RATE REQUIREMENTS

4.1 Data Rate Requirement

The required data rate is determined by the amount of data to be transferred, the protocol used to package the data, the data processing time, the channel access scheme and the time segment in which data is being transmitted. This analysis estimates upper bound data rates by assuming worst-case overhead rates and maximum retransmissions for messages adapted from the ITS Architecture and CVO requirements documents. We have also assumed a frame-based (TDMA -like) protocol, as this appears to be the direction the industry is moving.

Since the publishing of the previous paper, much work has been done on refining message content estimates and forecasting operating parameters. The data rates computed in the previous paper have been revised using the latest information on current systems, user requirements and developing standards to establish assumed values for the following underlined parameters. The parameters that are not underlined were computed from the underlined parameters:

- Capture Zone - length of the roadway over which the beacon antenna can create the proper signal level to enable communications - in feet;
- Speed - maximum vehicle speed during which communication shall be possible - in feet/sec;
- Message No. - number of messages passed for each transaction;
- Overhead - fraction of the message protocol not used for carrying application data;
- Processing Time - time used to compute the response to the messages - in seconds;
- Read Time / Frame - time in which the message data of each frame must be read - in seconds;
- Max Read Time - time that the vehicle is in the capture zone or, if the vehicle speed is zero, maximum time allowed for the transaction to occur (values for moving vehicles were computed) - in seconds;
- Frames Used - number of communications units (frames) used to send the messages;
- Slots/Frame - number of message data sections in each frame;
- Max Slot Data - maximum number of bits sent in each frame - bits;
- Msg 1 Size - number of bits in the first message of a transaction (downlink) - bits;
- Msg 2 Size - number of bits in the second message of a transaction (uplink) - bits;
- Msg 3 Size - number of bits in the third message of a transaction (downlink) - bits;
- Msg 4 Size - number of bits in the fourth message of a transaction (uplink) - bits;
- Total Size - number of bits in all the messages - bits; and
- Data Rate - maximum rate needed to send any one message in a transaction.

Figure 21 shows the relationship of the communication components in a lane-based transaction scenario. The lane-based scenario involves a short capture zone and communication with only one vehicle at a time. Figure 22 shows the relationship of the communication components in an open-road-based transaction scenario.

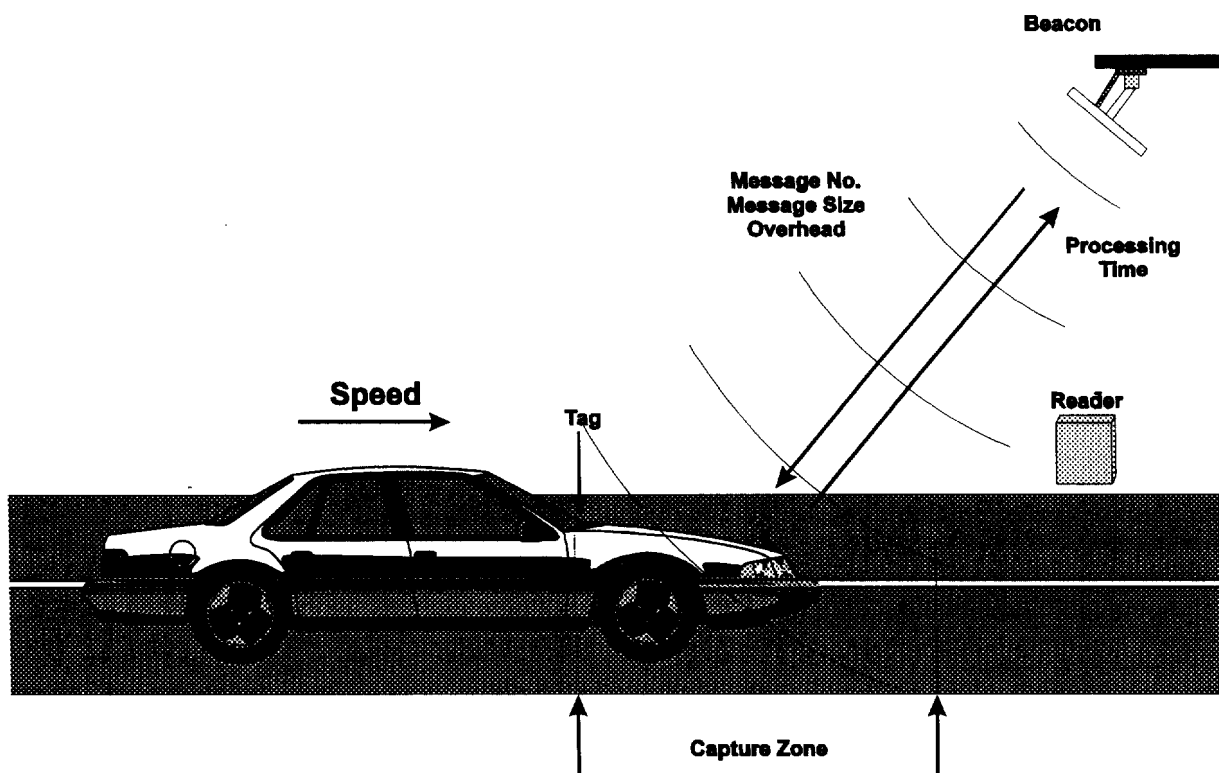


Figure 21. Lane Based Transaction Scenario (Single Communication Session)

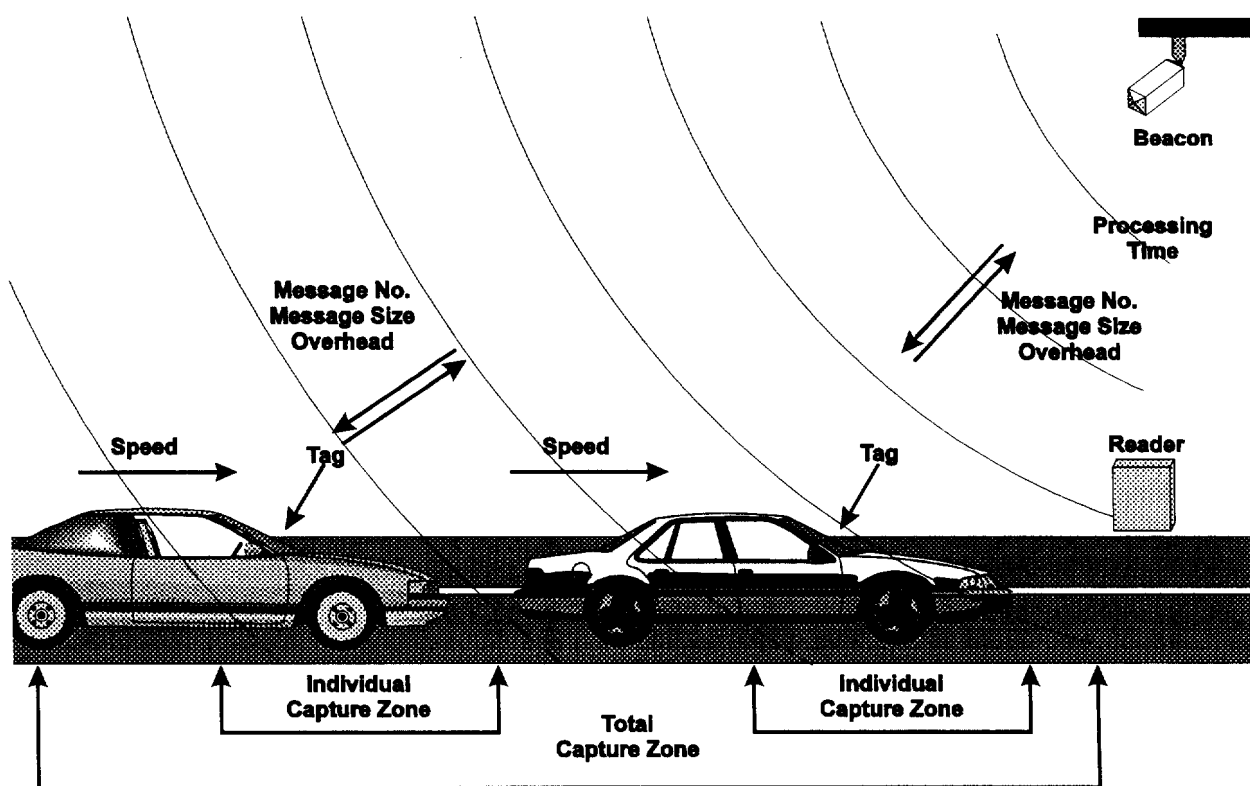


Figure 22. Open Road Transaction Scenario (Multiple Communication Sessions)

The open-road scenario includes a large capture zone in which it is possible to accomplish multiple transactions. The overhead is usually larger in this scenario than in the lane-based scenario because a significant amount of time is used to determine the access timing of the vehicles.

Table 4 lists the value of the parameters used for each transaction. The possible communication time was estimated by subtracting the processing time estimate from the time the vehicle would spend in the capture zone at maximum speed. For those transactions where the vehicle speed is expected to be zero, a default time limit, measured in seconds, was selected. The time actually spent transferring data (read time/frame) was then approximated by dividing the possible communication time by the number of frames and retransmissions needed to send the messages plus an extra net entry frame. The extra frame allowed the vehicle to enter the capture zone and receive the beacon signal until the beginning of a frame started. This allowed the tag to receive the all data in the starting frame correctly. The calculation always used two as the number of allowed retransmissions. Then the overhead was applied to the result. Each frame was assumed to be timed for a fixed data slot capacity in multiples of 560 bits. So, if the message data sent in a frame was 193 bits the frame would still take 560 bit time intervals to deliver the data. Therefore, the data rate was estimated from the number of message bits allocated in the timing of each frame and not the actual bits sent in the frame. The approximate data rate was computed by dividing the total number of bits allocated to each frame (Max Slot Data) by the available read time for each frame. The number of bits came from a hypothetical message set created for each transaction currently anticipated to be used for the ITS DSRC applications, see Appendix F. Messages from currently deployed applications were used as reference. However, the currently deployed applications use many different data sets, protocols and implementation procedures. Also, they do not represent all the functions that are expected to be deployed. Therefore, the message database represents an approximation of the data actually expected to be communicated.

Table 5 lists the transactions, applications, number of bits to be sent in the downlink (beacon to tag), number of bits to be sent in the uplink (tag to reader), the total number of bits to be sent (total size), and the data rate necessary to accomplish the transfer. The total number of bits to be sent includes both the downlink and uplink count of bits. The uplink bit count is smaller than the downlink bits for some transactions and larger than the downlink bits in other transactions. Therefore, the data rate is considered the highest rate required to send any of the messages in the transaction evaluated. The data rate must allow one transmission and up to two retransmissions, when necessary, in the time the vehicle is in the communication zone. The data to be transferred includes all ancillary characters like headers, transaction code, message length and Cyclic Redundancy Check (CRC) as well as the transaction data.

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Table 4. Transaction Par

ID	Transaction	Capture Zone (ft)	Speed (ft/sec)	Message No.	Overhead	Processing Time (seconds)	Read Time /Frame (seconds)	Max Read Time (seconds)	Frames Used
1	Toll Payment	10	182.3	3	0.69	0.020000	0.001201	0.055	3
2	Obtain Parking Fee	10	0	3	0.69	0.040000	0.029760	1.000	4
3	Parking Payment	10	0	3	0.69	0.020000	0.030380	1.000	4
4	Drive-Thru Payment	10	0	3	0.69	0.020000	0.030380	1.000	4
5	Sign Data	16	182.3	3	0.89	0.000100	0.000964	0.082	4
6	Border Clearance	30	182.3	3	0.89	0.040000	0.001370	0.165	4
7	Lock Tag Data	5	182.3	2	0.69	0.000100	0.001210	0.027	3
8	Screening	30	182.3	3	0.77	0.040000	0.002865	0.165	4
9	Safety Inspection	10	0	3	0.69	0.001000	0.030969	1.000	4
10	Safety Data Upload	30	182.3	2	0.89	0.000100	0.002584	0.165	3
11	Access Control	10	0	3	0.69	0.010000	0.030690	1.000	4
12	Driver's Daily Log Upload	10	0	2	0.69	0.000100	0.044281	1.000	3
13	Registration Data Upload	10	0	3	0.77	0.010000	0.022770	1.000	4
14	Signal Preemption	16	182.3	3	0.89	0.000100	0.000964	0.082	4
15	Signal Priority Request	16	182.3	3	0.89	0.000100	0.000964	0.082	4
16	Transit Fleet Status	10	0	3	0.69	0.100000	0.021462	1.000	5
17	Traveler Information	10	0	2	0.54	0.100000	0.067231	2.000	5
18	Fare Enforcement	10	0	4	0.54	0.000100	0.016880	4.000	37
19	Transit Vehicle Conditions	10	0	2	0.69	0.000100	0.044281	1.000	3
20	Transit Vehicle Passenger And Use Data	10	0	2	0.69	0.000100	0.028180	2.000	8
21	Driver Instructions	10	0	1	0.54	0.000100	0.057497	2.000	6
22	Advance Payment For Services	10	0	3	0.69	0.000100	0.019373	1.000	6
23	Update The In-Vehicle Kiosk	10	0	1	0.54	0.000100	0.004191	60.000	2196
24	Fare Payment (Credit Card)	10	0	2	0.69	1.000000	0.031000	2.000	4
25	Fare Payment (SMART Card)	10	0	3	0.69	0.040000	0.022892	1.000	5
26	AHS Vehicle Data	10	0	2	0.69	0.001000	0.023822	1.000	5
27	AHS Control Data Update	20	182.3	3	0.54	0.000100	0.003878	0.110	5
28	AHS Check Response	20	182.3	3	0.54	0.000100	0.003878	0.110	5
29	Speed And Headway	16	182.3	2	0.89	0.000100	0.001378	0.082	3
30	Vehicle Probe Data	16	182.3	2	0.89	0.000100	0.001378	0.082	3
31	Intersection Status	16	182.3	3	0.89	0.000100	0.000964	0.082	4

ction Parameters

Frames Used	Slots /Frame	Max Slot Data (bits)	Msg 1 Size (bits)	Msg 2 Size (bits)	Msg 3 Size (bits)	Msg 4 Size (bits)	Total Size (bits)	Data Rate (bits/sec)
3	1	560	72	240	124	0	436	466453
4	1	560	72	80	124	0	276	18817
4	1	560	72	240	124	0	436	18433
4	1	560	232	232	276	0	740	18433
4	1	560	72	175	136	0	383	580707
4	2	560	88	200	131	0	419	408699
3	1	560	56	109	0	0	165	462730
4	2	1120	88	1042	310	0	1440	390929
4	1	560	88	151	156	0	395	18083
3	1	560	56	162	0	0	218	216682
4	1	560	72	175	72	0	319	18247
3	1	560	72	180	0	0	252	12646
4	2	1120	80	712	312	0	1104	49188
4	1	560	72	88	104	0	264	580707
4	1	560	72	88	104	0	264	580707
5	1	560	64	72	696	0	832	26093
5	4	2240	2456	2456	0	0	4912	18265
37	4	2240	72	480	88	73784	74424	132699
3	1	560	72	476	0	0	548	12646
8	1	560	72	2944	0	0	3016	19872
6	4	2240	9272	0	0	0	9272	32252
6	1	560	72	1288	376	0	1736	28906
2196	4	2240	4915808	0	0	0	4915808	534409
4	1	560	648	64	0	0	712	18065
5	1	560	648	72	64	0	784	24462
5	1	560	72	1241	0	0	1313	23507
5	4	2240	72	205	4152	0	4429	577546
5	4	2240	72	205	4153	0	4430	577546
3	1	560	72	110	0	0	182	406495
3	1	560	80	193	0	0	273	406495
4	1	560	72	193	116	0	381	580707